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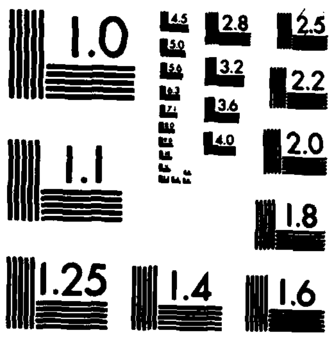

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The research under this grant centered upon two distinct but complementary approaches to the problem of developing implementable non-diverging nonlinear filtering algorithms: (1) decentralized linear filtering approach, and (2) adaptive extended Kalman filtering approach.

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FINAL REPORT

Grant: *AFOSR-74-2618 ADAPTIVE STRATEGIES IN NONLINEAR FILTERING*

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SUMMARY

The research under this grant centered upon two distinct but complementary approaches to the problem of developing implementable non-diverging nonlinear filtering algorithms: (1) decentralized linear filtering approach, and (2) adaptive extended Kalman filtering approach.

Primary emphasis was placed upon the first approach, and significant new results have been obtained (e.g., see [1,2,3,4]). These results describe techniques of sharing the required filtering effort among several low-order linear filters, and are potentially useful either for low-order highly complex systems or for high-order systems. The results were developed in a general format so that a wide range of aerospace problems could be accommodated--the primary requirement being that the associated systems be amenable to linearization. The first phase of this approach focused attention on the development of approximations which are optimal in a well-defined sense. The basic approach in treating the dimensionality problem has been to "optimally decentralize" the filter. The structure of this decentralized filter along with computational algorithms for the filter design and qualitative conditions for acceptable performance have been reported in [1-2]. Further results regarding the stability of the filter and extension of the filter to handle bias disturbances were given in [4].

Our most recent work has been concerned with the comparison of the optimal decentralized filter with other approaches to the

dimensionality problem. Through analytical and computational results we have demonstrated one mechanism (unmodeled interaction measurement noise) via which divergence of the reduced-order Kalman filter can occur. It has also been shown that the use of the optimal decentralized filter will provide estimates whose actual error covariance is smaller than that of the reduced-order Kalman filter. Thus the decentralized filter can often be effective in controlling divergence.

Recently Sorenson and Sacks [7] and Anderson [8] have suggested a fading memory or data discounting approach to the divergence control problem. It has been possible to show that the optimal decentralized filter is, in a sense, a generalization of the filter obtained from the application of the fading memory approach. These results, including a numerical study comparing the optimal decentralized filter with an optimal fading memory filter, appear in [3].

Relative to the problem of uncertainty in the system parameters it appears that the approach taken in the decentralized filter may be useful in implementing a generalization [9] of the compensation approach taken by Athans in [5]. Here it has been found necessary to remove certain restrictions [1] introduced in the decentralization of the filter.

The second approach was designed to apply to aerospace systems not so readily amenable to linearization. The initial phase of this approach is based in part on an extension of the technique developed in [5]. Briefly, [5] involved considering the

problem of compensating for steady-state filtering errors caused by unknown but constant errors in the plant parameters. That development was restricted to linear time-invariant systems with known constant inputs.

It is interesting to note the similarity of the structure developed in [5] with that of [6], obtained when compensating the standard Kalman filter for time-varying bias. It should be pointed out that neither of these results is a special case of the other one. Our future research plans include developing a more general formulation that includes each of these results as a special case. In order to handle a reasonably large class of nonlinear aerospace problems it is necessary to remove several of the restrictions imposed in [5]. Some of this work has been accomplished, but much remains to be done. Reference [10] describes our most recent results. The algorithm described therein has not as yet been tested relative to its effectiveness when applied to a problem of realistic complexity.

The next phase of this second approach to adaptive nonlinear filtering involves the problem of minimizing, in so far as possible, the filter's sensitivity to initial and reinitialization errors is approached by employing a team of extended Kalman filters, whose task it will be to adaptively control the system innovation process. The basic idea, briefly, is to desensitize the filter to initialization and reinitialization errors via diversity. That is, operating in parallel, each local filter, F_i, will track its best estimate, $\hat{x}_i$, of the system state, x,

conditioned upon its estimate, $\hat{x}_{i0}$, of the initial state x_0. Over each of a discrete set of time intervals, the residuals, $r_1,\ldots,r_N$, will be utilized to select a best estimate, $\hat{x}$, of the state, x, over that interval. Although at this time our thoughts are somewhat preliminary in nature, it is clear that this sort of approach can be implemented for real-time application, and, in fact, we have already developed the general outline of two such possibilities.

Much remains to be done in both of these approaches, but the basic framework of the required future research has been established. As in most research projects, this is the most difficult phase. The details of our future plans are described in the proposal "Methods in Adaptive Nonlinear Filtering" recently submitted to you.

As a final comment, relative to our research productivity, we have kept pace with our previous work under AFOSR sponsorship (over 10 publications during the past year, and over 40 since 1971 ... see the attachment for details). We would sincerely appreciate the opportunity to continue this association.

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